Three-Dimensional Vectorial Time-Domain Computational Photonics

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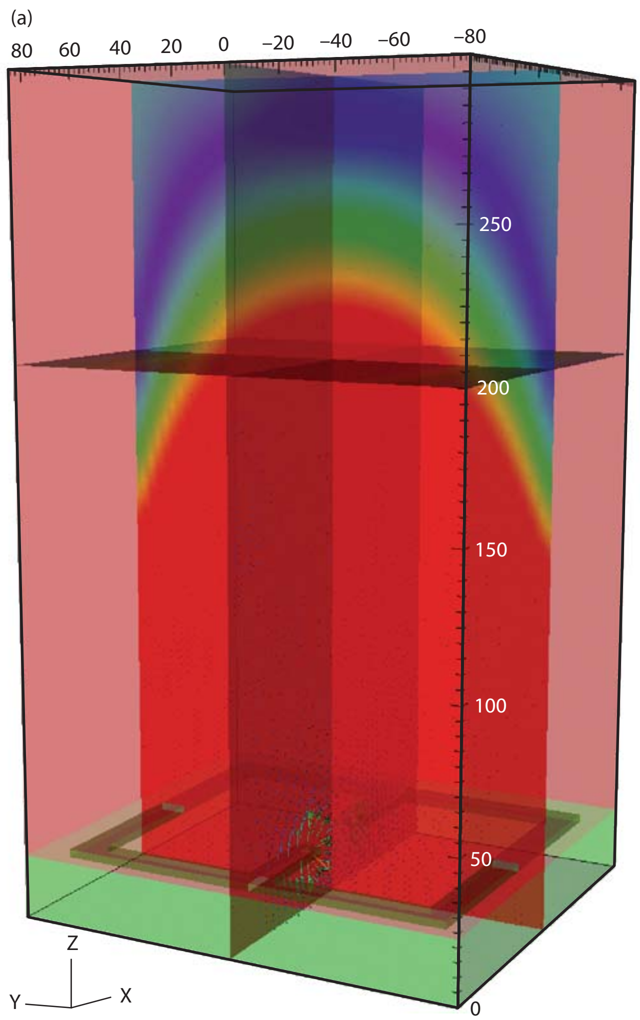

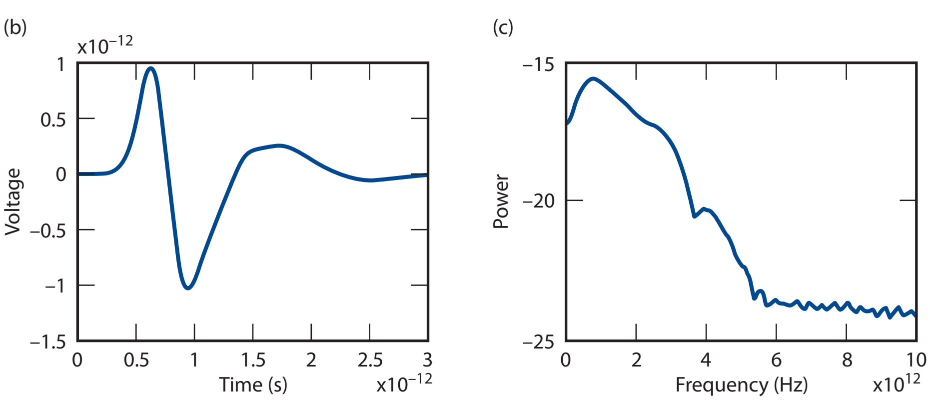

Figure 1. Field propagated from a Gaussian-triggered Auston-Switch THz source. The antenna and field emitted from it are shown in (a). The time history of the field at an on- axis receiver is shown in (b). The temporal spectrum of the field is shown in (c).

Customers with requirements for secure data transmission, computer networking, and high-bandwidth instrumentation are accentuating the need for photonic integrated circuit (PIC) technology. PICs will be the high-speed processing chips of the future and will impact both commercial and LLNL programmatic needs. Compact (LSI to VLSI), low-latency (sub-ps), wide-bandwidth (THz), ultrafast (100 Gb/s) miniaturized digital-logic, transmission, and sensor systems are potentially feasible. The design of novel integrated structures poses a considerable challenge, requiring models incorporating both microscopic and macroscopic physics.

Despite the strong photonic modeling capability at LLNL, new numerical methods are necessary as more complex photonic devices, materials, and configurations are devised. Three-dimensional time-domain (TD) design tools are fundamental to enabling and accelerating technologies for the realization of all-optical logic systems for data generation, transmission, manipulation, and detection. We have been doing the research necessary to create these new numerical methods.

Project Goals

We are filling the gap between existing modeling tools and those needed for LLNL missions by extending the state of the art in simulation for the design of 3-D PICs. We have defined challenges that must be addressed in our codes, such as models for optical gain and nonlinearities, as well as microscopic, nonuniform, inhomogeneous structures. Our tools leverage LLNL's expertise in computational electromagnetics (CEM) and photonics. We have developed models and algorithms for incorporation into a new generation of 3-D simulation tools. These tools are general enough to be adapted to problems in many areas, and flexible enough to embrace the design of future mixed-signal systems as well as stand-alone systems in disparate regions of the EM spectrum.

Relevance to LLNL Mission

The ability to model complex 3-D photonic devices in the time domain is essential to LLNL for a broad range of applications. These include high-bandwidth instrumentation for NIF diagnostics; microsensors for weapon miniaturization within the DNT programs; encryption devices and circuits for secure communications for NHI surveillance applications; high-density optical interconnects for high-performance computing (core of the ASCI mission); and detection devices for homeland security.

FY2006 Accomplishments and Results

Most of our work has been concentrated in extending our two research codes: Quench3D and EMSolve. Quench3D is a narrow-bandwidth scalar beam-propagation-method code built for modeling large devices in which light propagates in a preferred direction. EMSolve is a vector time-domain code used for modeling small devices with either complicated geometries and/or no preferred direction for propagation. In support of both of these codes we have also been working on a program to generate accurate gain and absorption curves for semiconductor quantum wells as a function of quantum well structure, wavelength, and carrier density.

In the past year we spent time researching algorithms for incorporating a vector finite element beam-propagation solver and a finite element carrier-diffusion model into the Quench3D suite. The incorporation of vector finite elements into the BPM solver will allow us to model the dependence of gain on polarization in amplifier and laser structures. In addition we spent some time determining how the code should be parallelized.

We researched the algorithms necessary for incorporation of carrier diffusion and polarization models for 2- and 4-level absorption/gain in the EMSolve suite. We also performed research on submesh modeling of carrier effects in EMSolve. These codes can be used to efficiently examine power scaling in Auston-Switch-based THz sources and model Vertical Cavity Surface Emitting Lasers (VCSELs). Using the results of this research we were able to simulate the power scaling effects of Auston-Switch-based THz sources. Figures 1 to 3 illustrate the results of this work.

The quantum well modeling code work primarily involved researching extensions and corrections to the groundwork that had been laid in the summer of FY2005.

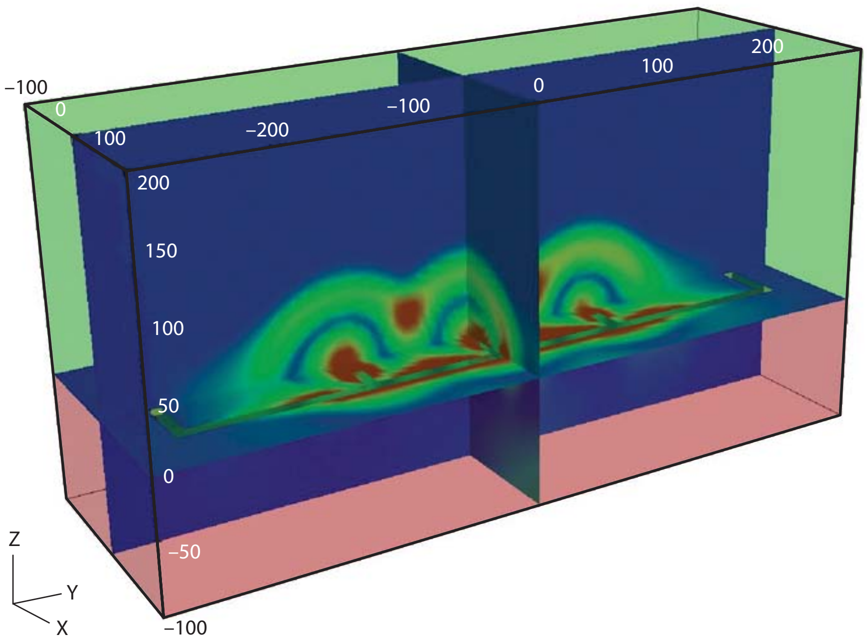

Figure 2. Field propagated from a trio of Gaussian-triggered Auston-Switch THz sources.

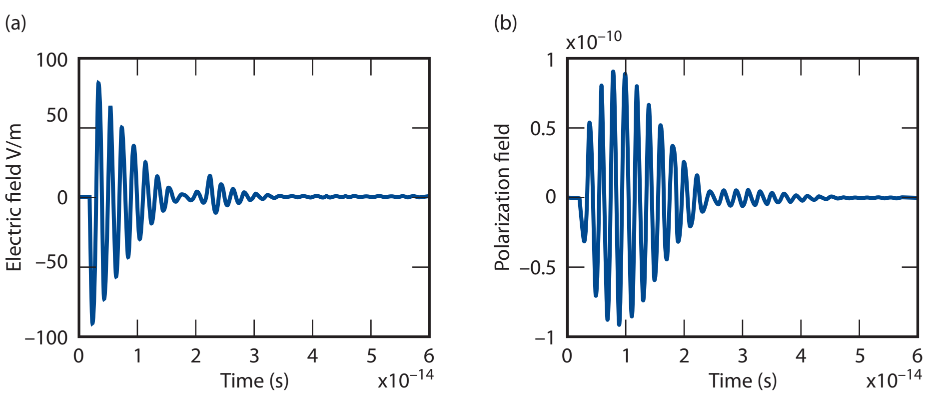

Figure 3. Electric field (a) and polarization (b) for a 2-level material illuminated by a beam of EM radiation. The polarization is computed using an auxiliary differential equation and is important in determining the gain and/or absorption in VCSEL simulations.

Related References

1. Bond, T. C., and J. S. Kallman, "Time-Domain Tools for the Investigation of Gain-Quenched Laser Logic," *International Semiconductor Device Research Symposium*, Washington, DC, December 10-12, 2003.
2. Koning, J. M., D. A. White, R. N. Rieben, and M. L. Stowell, "EMSolve: A Three Dimensional Time Domain Electromagnetic Solver," 5th *Biennial Tri-Lab Engineering Conference*, Albuquerque, New Mexico, October 21-23, 2003.
3. Koning, J. M., "Terahertz Photo-Conductive Antenna Array Power Scaling Simulations," *Proceedings IEEE APS*, pp. 2631-2634, 2006.